As the aims of this report have not been published. Any author desiring to quote this paper should refer to it as "A paper of the Meteorological Research Committee (London), M.R.P. No..... by Mr.....
A copy is available in the Library of the Meteorological Office."

M.R.P. 721.
S.C.II/106.
26th February, 1952.

AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE.

METEOROLOGICAL OFFICE
31 JAN 1953
LIBRARY

Review of Long Range Forecasting Methods

by

J.M. Stagg (Meteorological Office).

Introduction.

This review is concerned with methods that have been proposed or explored for the preparation as a regular procedure of forecasts for periods longer than can be dealt with by extension of normal day-to-day synoptic practice. To emphasise the difference between the precise and definite forecasts aimed at in short period methods and the kind of statement in general terms which is the most that can be expected from any long range system at present in sight, new words should be introduced. "Forecast" and "forecasting" will however be used in this review with their usual meteorological sense appropriately broadened.

The principal processes and phenomena that have been tried or suggested, singly or in combination, in the preparation of long range forecasts are:

1. Regression equations and multiple correlations.
2. Pressure waves.
3. Symmetry patterns.
4. Climatic singularities.
5. Pressure trends and other trend phenomena.
6. Long waves in the zonal circulation.
7. Kinematics of air flow and pressure cells.
8. Analogues and the repetition of synoptic patterns.
9. Solar phenomena.
10. Atmospheric ozone.

1. Regression equations. Relationships expressed in the form of multiple correlations or regression equations between future weather events in one region and present or past events in the same or other regions have been applied to forecasting in various parts of the world, particularly India, U.S.A. and Germany. The method depends on finding close connections between the element to be forecast and other elements or processes (such as the Southern Oscillation), and on the persistence of each of the constituent correlations. Because few of the relationships among meteorological events are simple or direct, especially when they are

/separated

M.R.P. box

separated in time as they have to be for application to forecasting, the correlations are liable to be unstable, and therefore the regression equations require to be modified from time to time so that new or improved correlations may replace those whose validity has deteriorated.

In regions where large scale processes like a monsoon dominate weather for several months at a time, regression procedures have proved of value in assessing whether such elements as temperature or rainfall are likely to be substantially above or below normal. But even in these regions, the correlations are seldom stable and though the physical processes behind the regression equation may be broadly understood the relationships are purely statistical so that the forecaster who uses them can exercise only such discretion and judgement as is allowed him in the formulation of the forecast.

The search for correlations among meteorological parameters in different parts of the world can improve understanding of the functioning of the atmosphere, and the use of regression equations can be helpful in conjunction with other methods, for example in relating the amount of ice in the north west Atlantic in the spring and early summer months to the mean latitude of depression tracks in the north east Atlantic later in the year. But forecasting by this means alone cannot lead far, especially in a meteorologically complex area like the British Isles, even if the correlations were elaborated and extended to take account of the more recently available upper air parameters.

2. Pressure Waves. Analysis of barograms of surface pressure from stations in middle and high latitudes can provide evidence for the existence of apparently regular wavelike oscillations whose principal periods are approximately 72 and 48 days and their submultiples. If the existence over a sufficiently wide area of one or more of these wave trains can be diagnosed early enough, it may be used to estimate future pressure at a network of stations and so lead to a forecast surface pressure chart. A similar procedure has been applied to pressure height contours at 500 mb. and higher levels. Pressure waves have been extensively investigated and applied to long range forecasting in Germany where indeed other important properties have been attributed to particular waves. For example the 72 and 36 day waves are believed to extend into the stratosphere and exercise control over the direction of travel of the 6 day wave and the movements of the centres of the 24 hour isallobaric pattern: the amplitude of the 24 day wave on the other hand decreases rapidly with height and is conspicuous only in the high latitudes. Pressure waves have also been investigated in this country.

Postulating a single or double layered atmosphere having prescribed kinds of temperature structure it may be shown that the atmosphere can oscillate in a number of periods ranging from 6 to 72 days, and also that the oscillations are propagated from west to east in middle and high latitudes. There is no unanimity about the origin of these oscillations: they have been variously attributed to unstable gravitational waves between troposphere and stratosphere induced by extension upwards of instability waves on the polar front, to roughly periodic outbreaks of cold air from the polar calotte or the breaking away of cold pools, to waves dependent upon the temperature differences between the main land and sea masses around zones of the earth, and even to precession movements in the wind circulation zones around the earth set up by unsymmetrical pressure fields, tilting the wind belts out of their appropriate latitude. No one of these explanations is physically satisfactory or complete.

But even without a satisfactory physical basis the existence of regular trains of periodic oscillations might be of value in forecasting if they were sufficiently regular, of big enough amplitude and sustained over long enough intervals. Unfortunately these requirements are seldom, if ever, all met.

/The

The wavelengths of the dominant waves vary over a considerable range and a sequence of oscillations seldom continues more than three or four cycles: the use of the word wave (in the sense of a sustained and regular recurrence pattern) in connection with the tendency of the atmosphere to oscillate is misleading.

It has to be concluded that wave-like oscillations of the atmosphere probably do exist and that further study may well be valuable as likely to give further information about the structure and behaviour of the atmosphere; but pressure waves are too transient, irregular, and perhaps localised, and variable from season to season and year to year to be of assistance in forecasting.

3. Symmetry Patterns. From time to time the pattern formed by a sequence of barograms at a station over an interval of a month or more from a particular date is roughly a direct, or less frequently an inverted, mirror image of the pattern before that date. When this occurs the patterns at other stations in the same region show similar characteristics, and the pattern as a whole appears to be translated into other areas as if it were embedded in the circulation. If a pattern of this kind can be recognised before, or by the time of, the central date as likely to be a symmetry pattern, harmonic or other analysis can be employed to extend the pattern into the future at a network of stations and so allow it to be applied to forecasting the surface pressure distribution.

The chief components in a symmetry pattern are found to be the same as in pressure waves, viz. 72 days and its submultiples, and the pattern is therefore explained by the simultaneous existence of pressure waves, phased so that the extreme minimum or maximum values all coincide at the point of symmetry.

If this is the only physical explanation of symmetry patterns - and it fits the facts - then the value of their application to forecasting is as precarious as is the use of pressure waves. There are however some further aspects. The 24 day wave is one of the most dominant constituents of every symmetry pattern and this, as explained in the preceding section, has been attributed to major outbursts of polar air from the Arctic basin: if there is a tendency for these outbursts to occur at about 24 day intervals, the occurrence of a roughly symmetrical pattern a few times each year may express little more than the tendency for one prolonged weather type (e.g. south westerly, with its series of depressions each having its particular family characteristics) to be interrupted by a polar air outburst. This leaves open the questions whether the polar air surges do have a 24 day rhythm, even if only for two or three cycles, and whether, if there is an approximate rhythm, it is inherent in the build up and break down of pressure over the polar cap, or whether it is started by a smaller and less spectacular tendency for the atmosphere to oscillate naturally at about 24 day intervals. There is so much doubt about the answers to these questions, and indeed about any system which depends on the analysis of an element like pressure having intrinsic coherence in its day to day variation that some authorities have concluded that symmetry patterns are the result of fortuitous circumstances in the pressure field. All but a very few patterns are recognisable only after detailed analysis; they are found only a few times a year, mainly in winter.

To be of value in forecasting the existence of a pattern and the symmetry date must be known as soon as possible after the central point of symmetry has been reached and its main features must be reproducible by a few of the harmonic components. But there is no known method of forecasting the symmetry date, and even if there were the lack of persistence in the pattern and uncertainty about its form and amplitude after the central date make the information of very doubtful value. Methods have been devised and applied both in Germany and in this country by which the

/pressure

pressure field over a whole region can be analysed in means of one to three or more days but such statistical devices do not compensate for the inherent weaknesses of the method both in physical interpretation and practical application.

4. Climatic singularities. In probably every region of the world there is a tendency for particular types of weather or abrupt changes in its annual course to recur round about the same calendar dates each year. These singularities (as the German meteorologists who have studied them most have called them) include large scale phenomena like the beginning of the Indian monsoon or, at the other extreme, discontinuities in the otherwise smooth trend of mean temperature through the year such as were first discussed by Mossman and Buchan for south east Scotland. By classifying the type of surface pressure distribution over the British Isles on each day of the year for a long series of years Lamb has recently shown that many of the singularities listed by German meteorologists show up also in the weather of this country.

When the singularities are restricted to a comparatively few well-marked events each with a genuine physical basis there can be little doubt of their value in forecasting: the reality and value of many singularities become more questionable when their number is increased so that 6 or 8 are expected each month. It is admittedly dangerous to discount a phenomenon because it has no obvious explanation, and until more is known of the mechanism which leads to the major changes in the zonal circulation in middle latitudes of the troposphere, or what is probably the same thing, to the irregular interchanges of heat and momentum between the zonal circulations, the explanation of the high incidence of particular pressure distributions over an area on days linked with the calendar must be lacking. But the reality of individual singularities can be accepted and used as an auxiliary factor in forecasting only when their frequency of occurrence over a long series of years is substantially higher than random, and when some explanation, at least proximate, can be offered when they fail to occur or are much displaced from their place in the calendar.

Up to now the only explanation of singularities is in terms of pressure waves, particularly the 72-day wave and its submultiples. According to this, the wave processes determine the pattern of surface pressure distribution and through it the major changes from zonal to meridional circulation: on this theory the absence or displacement of singularities can be taken as a warning that another system of waves has been established or the phase altered and this in itself is a tool in the experienced forecaster's hand.

In current synoptic language many of the more important singularities in this part of the hemisphere are probably associated with "blocking" of the zonal westerlies: an intensive study of this phenomenon might therefore throw light on the cause of authentic singularities. Alternatively the study of real singularities, critically segregated from the merely fortuitous, might well be extended to the simultaneous events in the middle and higher troposphere and lower stratosphere: even though it might not lead to conclusions directly applicable to long range forecasting, a study of this kind would be one method of obtaining further experience of the three-dimensional behaviour of the atmosphere which could hardly fail to have applications to forecasting practice.

5. Pressure trends and other trend phenomena. As the amount of detailed information in a series of synoptic charts at 6, 12 or even 24 hour intervals is apt to conceal the slow though widespread changes that may be in progress it has been considered that the use of charts drawn to represent the deviation of the mean surface pressure distribution for a number of days from the long term normal distribution would bring these slower trends into prominence. Charts of pressure anomaly for various combinations of days have been used in

/this way

this way to identify centres of abnormally high or low pressure, and to study their movements with the object of extrapolating their trajectories. But the results of at least one experiment on these lines conducted by C.E.P. Brooks in this country using 6, 12 and 24 day mean charts were not encouraging.

A similar kind of procedure, though not using deviations from normal, forms part of other systems of forecasting. For example trends of index figures representing the strength of the zonal circulation have been applied to help in assessing the future circulation pattern, and surface pressure profiles at a network of stations are similarly used as a clue to the general trend of pressure over an area.

In these and other applications trend procedures are quite empirical, and for want of knowledge of the causes of the trend the bias in extrapolation must always be towards normal. It is therefore not surprising that the contribution of trend methods to long range forecasting procedures has not been found helpful; at best they can be only auxiliary aids.

6. Long waves in the zonal circulation. The working hypotheses which allow long wave ideas to be applied to forecasting are, firstly that the waves are more slowly variable and their immediate behaviour is a little more amenable to forecasting than the surface pressure field, and secondly that the main features of, and changes in, the surface field are related to the pattern of the upper tropospheric circulation. Unfortunately these hypotheses are not conspicuously reliable beyond the second or third day. The only approximately realistic theory of long waves so far developed rests on assumptions both as regards the physical characteristics of the medium and the nature of the undulations which the atmosphere seldom recognises, so that substantial empirical and subjective factors have to be superposed when the theory is applied in practice. Even then inferences can be made about speed and wavelength only of waves that already exist: little help can be given about the time and place of formation of new waves or about the intensification or decay and disappearance of old ones. For these aspects of the long wave pattern the forecaster must use the second hypothesis in reverse, and assess the changes in the pattern of tropospheric circulation that are likely to be brought about by the development and movement of surface features. And reliance on this interaction is impaired in that its extent depends among other things on the scale and intensity of the surface developments. Small and shallow depressions and high pressure cells are steered by the circulation pattern without altering it substantially, but the larger and more vigorous features of the pressure field impress their effects on the circulation.

Notwithstanding these weaknesses, techniques based on circulation theory and experience have contributed to the preparation of 5 and, more recently, 30 day forecasts in U.S.A. and 10 day forecasts in Germany. In Germany the technique adopted is a grafting of a step-by-step extension of daily synoptic practice for the first five days on to a forecast derived from a combination of other methods for the second half of each 10 day period. In U.S.A. 5 and 30 day mean configurations of the surface and upper air circulation patterns are dealt with as units, using step-by-step daily practice for the first 2 or 3 days as a check in the preparation of the 5 day forecast.

Apart from the uncertainties inherent in the use of circulation ideas, adaptation to 5 or more day mean patterns introduces further doubts. It can be contended that mean circulation charts for even as many as 5 days can have little physical significance, or more precisely, that the equations of circulation theory cannot be satisfied by means of meteorological elements which do not correspond with any real state. On the other hand

/those

those who use them claim that 5 and even 30 day mean circulation charts and their surface field counterparts have real physical individuality and that only mean charts can disclose the "centres of action" which regulate the longer period trends in weather: they claim that the results of long wave theory can be applied to mean charts with only a little more empirical modification than is already necessary for daily charts, and, further, that the broad features of weather, e.g. departure of temperature and rainfall from normal, can be inferred from the mean surface charts deduced from the mean charts of circulation. And in this connection it is appropriate to recall that monthly mean surface pressure charts for the British Isles have been officially published for many years.

Without experience of the use of mean charts it is difficult to be categorical about them: if experience were to confirm that they have physical significance, it might be expected that methods of dealing with them, either empirically or even theoretically, would be devised, keeping in mind that the inferences to be made would relate only to substantial departures from normal.

7. Kinematics of air flow and pressure cells. With their weather dominated for much of the year by anticyclones and their vast plains providing a natural laboratory for the study of air mass and pressure cell movements, it is not surprising that Russian meteorologists should have been led to base their system of forecasting on trajectories of high pressure cells. Though analogues and rhythms and to a minor extent dynamical reasoning also play an important part in the system begun by Multanovski (M) and elaborated by Pagava (P), the movements of anticyclonic cells and the pressure fields associated with them form the "natural" basis of their "natural" processes within "natural" regions.

According to the M-P school the anticyclonic nuclei that invade U.S.S.R. territory, come predominantly either from the Azores, from Greenland or from the Arctic basin via Taimyr. They have preferred axes along which they move and the frequency of invasion from each of the main centres and the orientation of their trajectories depend on the time of year and on the kind of season. In some years, for example those characterised by unusually mild autumns, the frequency and the orientation of the tracks followed are consistently abnormal.

Once a high pressure cell has started to migrate its future track is approximately known and by reference to charts which have been constructed to show the positions of the other high and low pressure cells relative to similar tracks followed about the same time in other years, the general form of the surface pressure distribution linked with a particular anticyclonic axis can be forecast. As the likely orientation of a high pressure cell trajectory can be determined within 2 or 3 days after the nucleus of the cell has appeared and as the average life of a cell is 10-12 days, it is possible by the M-P system to forecast 7 or 8 days ahead.

This period of 7-8 days can be extended by other considerations. At a time varying from 30 to 35 days before the start of a high pressure cell process, there are recognisable premonitory symptoms in the surface field, and in the interval between the appearance of these warnings and the start of the process there are several recognisable phases of 6 to 15 days each characteristic of a stage in the progress towards the main (high pressure cell) process. In addition the Russian long range forecasting school has discovered that there is a tendency to rhythms with still longer periods in the behaviour of the atmosphere. The principal rhythms are of 3 and 5 months' duration and are related to major outbreaks of air south or south westwards from the Taimyr area.

It is difficult to form a just appreciation of the M-P system of forecasting, and even if it were proved to be successful in Russia it does not

/follow

follow that it could be applied to any other areas because Russia's extent (east to west and into the Arctic basin) and surface topography relative to the general circulation, are unique. Nevertheless there are lessons to be learnt:

(1) Russian meteorologists have clearly made an intensive study of dynamical climatology on the lines sketched by Bergeron.

(2) As a sequel to this they have recognised and applied the idea of natural periods and natural regions; rejecting the week, month and season as their units of time they accept as their intervals for study the particular kind of weather process likely to be dominant. They make their composite charts, and base their procedure on these more (meteorologically) natural intervals and issue their forecasts accordingly.

(3) Stress is laid on the genesis, development and track of the anticyclonic cells. This may be as natural and as necessary in Russia as it is natural and necessary in an area situated like the British Isles to stress the role of depressions. But even in less anticyclonically controlled areas than Russia it might be rewarding to give more attention to the growth, migration and decay of high pressure cells.

8. Analogues and the repetition of synoptic patterns. In a sense the use of analogues is an important feature of all forecasting, short and long range alike: no forecaster can afford to ignore experience of apparently similar situations in the past, and as a means of conserving that experience and making it readily available when required it is no more degrading to use cards with holes or photographs on them than to use regression equations, or other arithmetical means of putting unexplained relationships into number form. The regression equation may indeed be regarded as the less helpful, whether it be used for assessing the speed and direction of upper wind at a place four hours after an observation or for the foreshadowing of rainfall in the Indian monsoon: the result of the arithmetic excludes judgement, but a well devised and efficient system of analogues leaves the forecaster scope for discretion.

In short range forecasting frequent observations, efficient communications and simple extrapolation go a long way to fill blanks in the forecaster's knowledge of the physical processes at work so that the use of mechanical means of aiding his memory or making up for lack of experience is not necessary, and is even to be deprecated. Physical reasoning should replace memory. But in the present state of knowledge of the major, longer term processes which control the weather over an interval of 10 days or a month, and until at least as much is known about them as about the 6, 12 and 24 hour processes, some system of summarising and recording experience is necessary if forecasts are to be made in turn by members of a team. The officer who devises the system may become sufficiently saturated with weather history and its modes of evolution to be able to rely on his experience as a guide for the future: but he has to make that experience available to others, and in default of an adequate theory a scientifically devised system of analogues may be as useful as any other.

Hitherto analogue systems have been mainly concerned with aspects of the surface pressure pattern and have used as their basis the relative dispositions of the main cells, or the origin and orientation of anticyclonic cells, or direction of the dominant air flow, or combinations of these. And in all intelligent use of analogues care has been taken (1) to ensure that the similarity has extended beyond instantaneous patterns to the immediately preceding development, and also (2) to take account of the part likely to be played in future development by the

/difference

difference in the earlier histories of the air masses in the pattern. Further, analogues have seldom been used as the sole guide. But from what is now known about the importance for surface weather of the upper troposphere and lower stratosphere, it is likely that these systems have been of indifferent value because they could not be extended to take into consideration the thermal or contour patterns relating to those higher layers.

It is not to be inferred from this that the present reviewer regards analogue systems as a necessary and much less a permanent technique in forecasting: on the contrary he has seen how valueless and misleading they can be in practice. But if it be accepted that a preliminary to starting any system of forecasting for periods more than 2 or 3 days ahead must be an intensive study (from a wider perspective than short period forecasting requires) of modes of evolution of particular types of thermal and flow pattern in the middle and higher troposphere and lower stratosphere the information derived from the study must be systematised. The best way to systematise it is to devise a comprehensive theory which takes account rigorously of the dynamics and thermodynamics of the whole field of interaction. But it is unlikely that that will be available for many years. So unless each member of the forecasting team is to make his own study, and build up his own background, an adequate system for comparing and grouping situations of like evolution is necessary - always keeping in mind that the system is only an interim measure and that the forecasting team must be weaned away from it at least as fast as physical knowledge of the underlying processes replaces empiricism.

9. Solar Phenomena. As regular seasonal changes in solar radiation so obviously affect the general temperature in each hemisphere and the tempo and intensity of weather changes, it is contended that the irregular changes in the sun's output of radiation which are assumed to vary in parallel with particular indices of its surface activity should affect weather to an appropriate degree. Much work has been done in many countries to discover relationships; mean annual and monthly and daily values of sunspot numbers, and of measures of the solar constant, numbers of faculae and other indices have been correlated with a great range of climatic and weather parameters. The results, though of interest for the light they shed here and there (or fail to shed) on indirect relationships between solar activity and terrestrial weather, are of no value for forecasting: the only reliable and persistent correlation so far found is between sunspots and temperature in the more cloudy regions of the tropics and this (negative) correlation shows up only in the mean annual values. More must be known about the relationships between measures of solar activity and the output of radiation from the sun in various spectral regions, particularly in the ultra violet, and about the possible effects of corpuscular radiation, before solar phenomena can be of use in forecasting: and even then it is not clear that it will be any easier to forecast behaviour on the sun than the behaviour of our own atmosphere, except perhaps in a general way for the 11 (or 22) year cycle.

10. Ozone. Although much is now known about the life history of atmospheric ozone, its distribution over the globe, the seasonal changes in that distribution and the intimate association between the distribution and the patterns of the surface pressure field especially in moderate and high latitudes, measurements of ozone are so far of value to the forecaster only as pointers to the nature of the upper air processes that accompany the birth, growth and decay of low and high pressure cells in the lower troposphere. Even if the redistribution of ozone by some extra-terrestrial influence preceded rather than accompanied the changes in the higher circulation pattern and surface field it would still be necessary to forecast the behaviour of the mechanism which effects the irregular changes in the amount and distribution of the ozone.

/11.

11. Conclusions. The only valid inference from the foregoing brief reviews is that no ready made procedure or combination of procedures exists which recommends itself as suitable for adoption in detail for long range forecasting in the British Isles. The objections are not only that most of the methods in use or that have been explored are primarily applicable, if at all, to large continental areas and also that they rely too much on empirical and impermanent relations with the subjective factor too dominant for them to be acceptable as a basis for a regular system in our area: the objection rather is that too few of them are founded on lines which will allow organic development into sound physical methods as knowledge of the atmosphere grows. Even with present knowledge of the complexity of the atmosphere and the interactions of its parts, any worthwhile system of forecasting beyond 2 or 3 days, like any modern system of day-to-day synoptic forecasting, requires the building up of an elaborate procedure and the accumulation of much experience in its use. Unless much effort is to be wasted it is therefore necessary to ensure that any new method to be started has an adequate physical background and is conceived with sufficient elasticity to permit modification for absorbing new ideas without wholesale abandonment of technique and experience.

Guidance on the choice of a system fulfilling this requirement would be at hand if a confident answer could be given to the question, where is the principal seat of those physical processes that result in, or have as their necessary concomitants, the changes in surface pressure distribution and associated fronts which have our weather as end products. Unfortunately that question remains open. But increasingly in recent years the zonal circulation in the middle and higher troposphere, its day-to-day, seasonal and annual changes in intensity and latitude, its maintenance and role in equalising the gains and losses of heat and momentum in adjacent zones and the relationship of its varied configurations with the surface pressure field - these have rightly assumed great importance. Progress in any of these aspects of the subject has potential significance not only in helping to provide an answer to the basic question: it cannot avoid having practical application to long range (as indeed also to short range) forecasting. It may well be that the zonal circulation in the upper troposphere is as dependent for its complete specification on what takes place in the lower stratosphere as it probably is on events nearer the earth's surface: but sufficiently detailed and extensive knowledge of the modes of interaction between the troposphere and stratosphere must await improvement of observational practice at high levels and can be grafted on to an adequately designed forecasting system as that knowledge becomes available.

If the foregoing line of thought is broadly right one inference appropriate to the present stage of our knowledge about what goes on in the higher (meteorological) atmosphere might be to defer setting up a long range forecasting system until we have a more generally acceptable conception of how the circulation works. A more justifiable inference is that the sooner a start is made in planning the strategy and the tactics of a system the sooner will the main problems fall into their proper priority for solution.

The design of a forecasting system is in part also determined by the period to be covered by the forecast and the intervals of issue. As explained earlier the Multanovski-Pagava school adheres to "natural" periods whose duration is defined by the time taken by the main weather processes to complete themselves: forecasts are issued at variable times adapted to these natural periods and any change from that procedure has resulted in reduced accuracy. A distant relative of this kind of procedure has been long in use in this country in the form of further outlooks, added to forecasts when circumstances allow. It is probably not regarded by the users as satisfactory and hardly constitutes a forecasting system. The aim

/should be

should be the issue at regular intervals of forecasts for fixed periods even though the period of issue has at first to be restricted to a particular season of the year.

In spite of the advantages of the variable "natural" period, it will be difficult in this country to ignore the month (or 30 day period) and its sub-divisions of 10 and 5 days: they have been found to be the most satisfactory elsewhere from the user's point of view and also for the practical aspects of the routine in preparing the forecasts and of the adaptation of existing statistics. But as the same basic system is to be used for all periods, it is clear on this reasoning that it should be designed with the aim of producing forecasts for 5 days in the first instance, developing to 10 and 30 day periods as opportunity and increasing knowledge allow.

Seasonal forecasts of useful value for this country are unlikely to be attainable for many years. And yet, by application of by-products (e.g. long term fluctuations in the mean latitude and intensity of flow of the westerly zonal circulation) of the studies that will be necessary for the main forecasting system it might be found that some very general information could be offered about departures from normal of such elements as temperature and precipitation.

It might of course turn out that the basic supposition underlying these conclusions is wrong and that the zonal circulation is unamenable to any physical or statistical treatment which will allow its intensity, position and configuration to be determined even 5 days in advance. It is already believed in some quarters that forecasting 2 or 3 days ahead may be impracticable because the zonal circulation, like the frontal waves in the lower troposphere is inherently unstable. If that were confirmed it might still be possible to give seasonal guidance and to supplement that at irregular intervals by information derived from a statistical examination of the various modes by which the zonal flow can change from one broad pattern to another.

12. Summary of Recommendations.

1. Any system of long range forecasting to be developed in this country should be based on the modes of behaviour of the zonal westerly circulation in the middle and higher troposphere, using contours at the 500, 300 and, if practicable, the 100 mb. levels, or the corresponding thermal patterns as the main working tools. The aim should be to issue forecasts in general terms regularly for 5, 10 and ultimately 30 day intervals, though not necessarily throughout the year.

2. As one method of determining the future configuration of the circulation pattern may be by mean charts, a study should be made of charts of contours at the 500 mb. and higher levels meaned for 5 or more days, with a view to (a) assessing their significance and potentialities for forecasting, and (b) devising ways of deriving the general form of each mean chart from the preceding sequence of mean charts.

3. Every use should be made of advance in knowledge about the processes (of heat and momentum interchange with the circulation of neighbouring zones) by which the middle latitude circulation is maintained and caused to vary. If practicable, contributions should be made to knowledge of these processes. The object would be to achieve a procedure by which abnormal influxes of heat or momentum into the zone could be detected as a routine procedure while in progress, and their effects on the intensity, latitude, distribution, etc. of the flow assessed.

4. As a means of gaining further insight into the modes of evolution of patterns of zonal flow in association with selected classes of surface pressure distribution, sequences of 500 mb. and higher level contour charts

/should be

should be analysed on days preceding the same authentic singularities in each year, and also on days preceding major changes of type.

5. Study should be made (perhaps by the Climatological Division working in close co-operation with the Forecasting Research Division) of the broad features and trend of weather, in terms of temperature, precipitation, etc. anomalies from normal, associated with mean surface pressure distribution for 5, 10 and 30 days. The purpose of this would be to allow statements of the expected weather to be quickly formulated after the mean surface pressure distribution has been deduced from corresponding mean contour charts. It might be

/found

found that the use of the intermediary surface pressure charts could in time be dispensed with.

6. In addition to continuing to accumulate experience of the ways in which the zonal circulation in the middle troposphere is affected by the development and movement of high and low pressure circulations in the lower troposphere and vice versa, study should be made wherever the network of observations allows of the corresponding interactions between the lower stratosphere and the main zonal circulation.